OCEAN-ATMOSPHERE INTERACTIONS

Eric Chassignet

Florida State University – COAPS

COUPLED OCEAN-ATMOSPHERE TIME SCALES

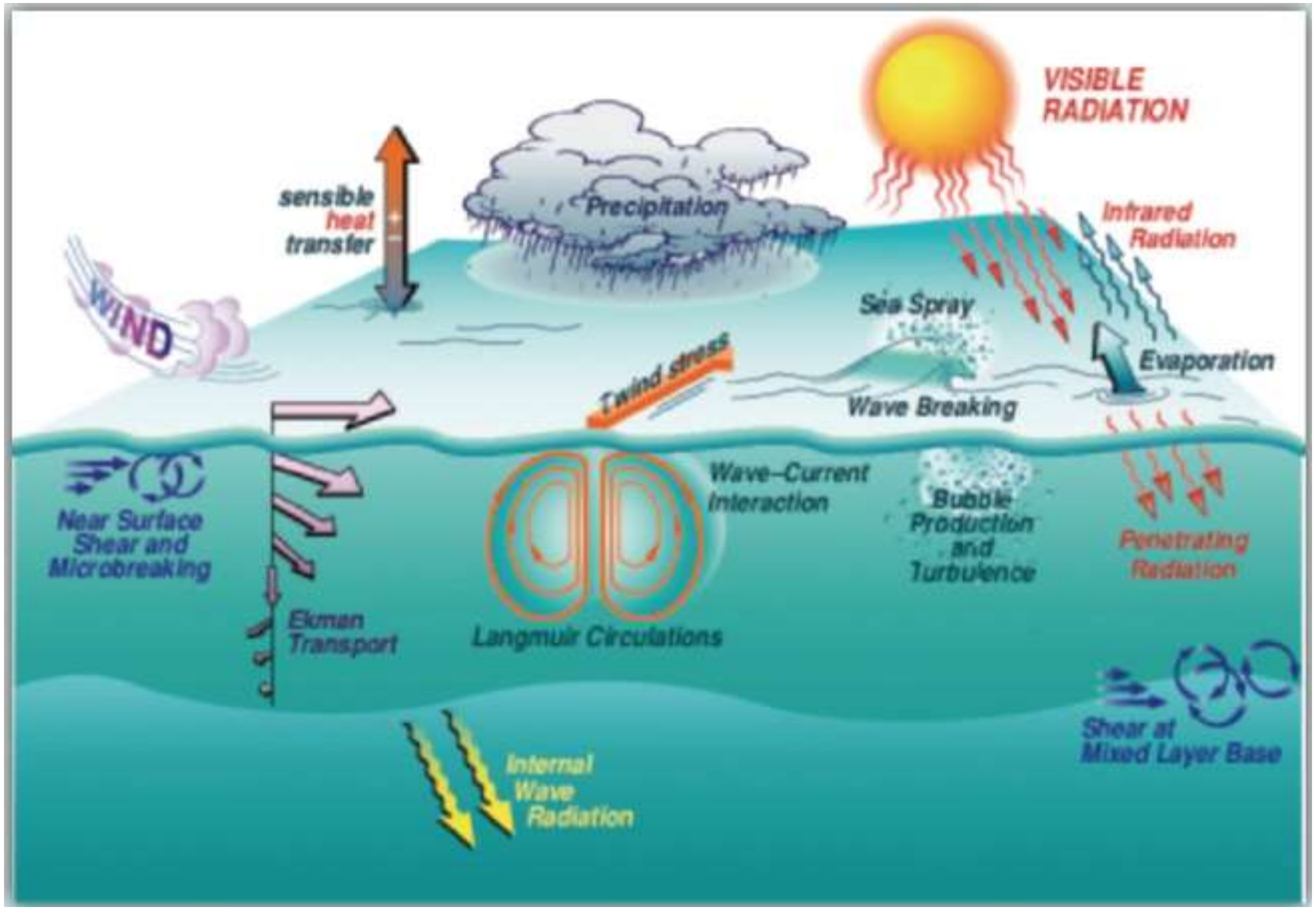
- S2S time scales as defined by NAS committee "14 days to 3 months"
- The ocean is often described as the flywheel of the Earth's climate (Visbeck et al, 2003). The ocean's large heat capacity (2.5 m of water contains as much thermal energy as the entire atmospheric column) acts as stabilizer for the Earth's climate. The ocean reacts more slowly than the atmosphere to changes in heat, but also stores this heat and releases it over longer time periods.
- Statistically, outside the tropics, the ocean has traditionally been found to react to the high frequency changes of the atmospheric forcing and that its influence back to atmosphere is weak on short time scales (Kushnir et al., 2002).

COUPLED OCEAN-ATMOSPHERE TIME SCALES

- However, one needs to distinguish between applications that are sensitive to slowly evolving boundary conditions (NAO, ENSO, etc.) and ones that are sensitive to rapidly evolving boundary conditions (diurnal cycle and MJOs, severe weather, etc.).
- Ocean-atmospheric feedback time scales that are on the order of days occur mostly in the turbulent surface layer (atmosphere, ocean, waves, and sea-ice) and over the continental shelf.
- The latter is where the highest biological and human activities are and where the majority of applications for ocean prediction take place.

COUPLED FORECAST ERROR

A significant portion of coupled forecast error can be directly attributed to errors in air-sea fluxes and associated parameterizations.



From Edson et al., BAMS 2007

SURFACE ROUGHNESS OVER GULF STREAM

SAR image showing convective cells over Gulf Stream: smooth waters over cool water (Sikora et al., 1995).

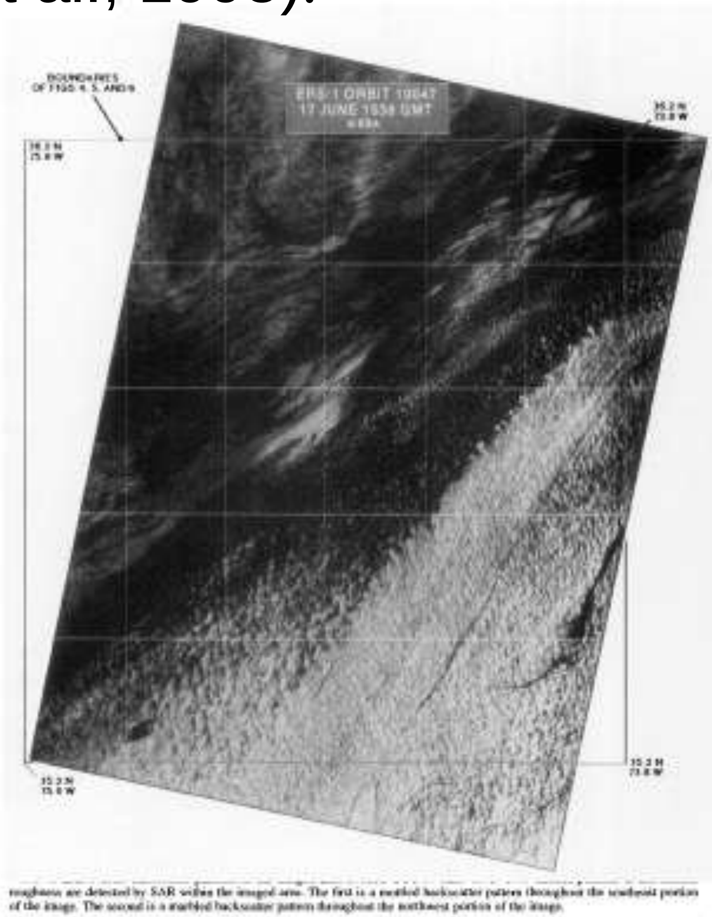
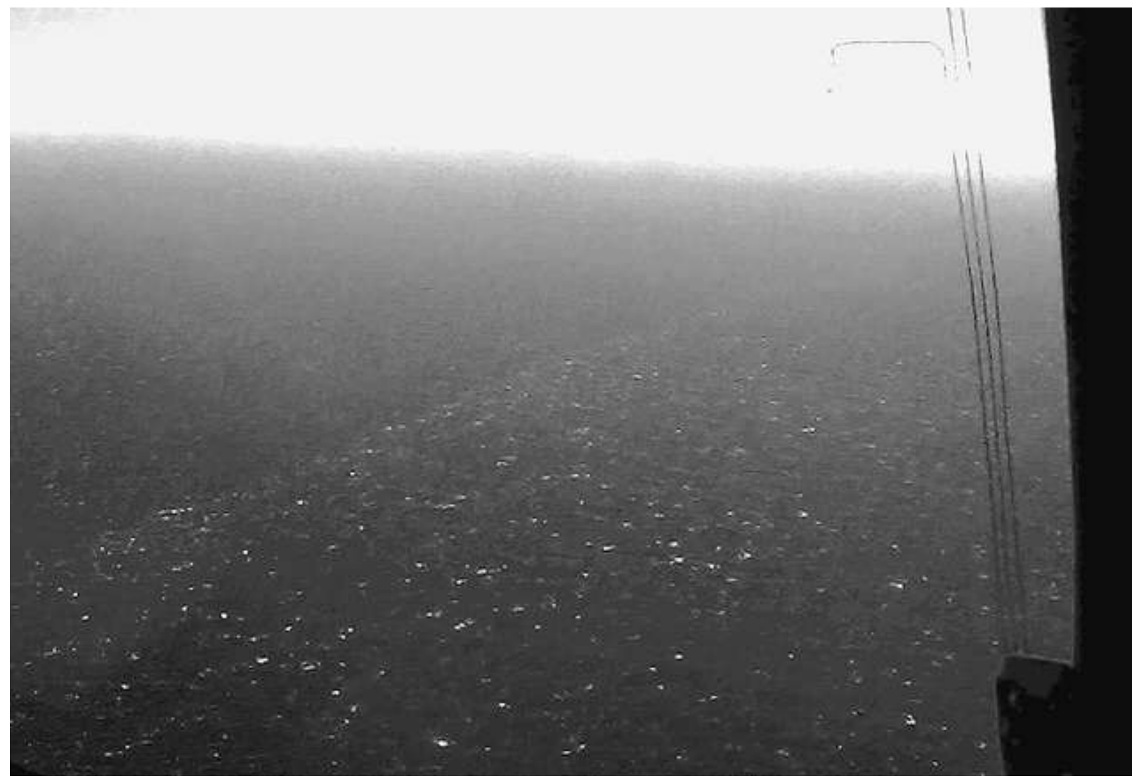


Photo taken over Gulf Stream looking towards cooler shelf waters. Courtesy P. Chang and D. Chelton.

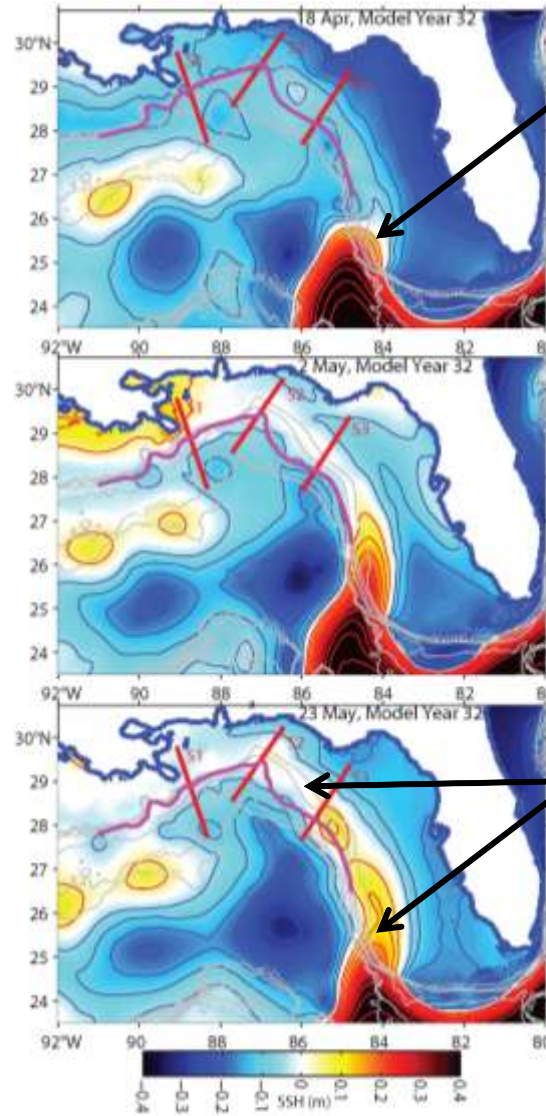


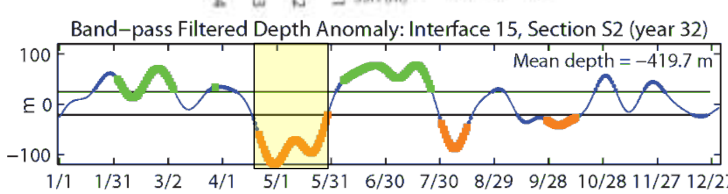
Slide courtesy of M. Bourassa, FSU

Cross-Slope Flows in the DeSoto Canyon

- Large-scale low-frequency downwelling events are 2 to 4 times more likely to occur when the Loop Current impinges on the continental slope along the southern West Florida Shelf, and upwelling events are more likely in absence of impingement.
- Loop Current contact with the continental slope spawns a high pressure (SSH) anomaly that transits the continental slope toward the Mississippi Delta in the topographic Rossby wave direction. This high SSH suppresses isopycnals below, causing downwelling and/or hindering upwelling.

Nguyen et al. (2015)





Tomas et al. (2011): Impact of a high resolution ocean in CCSM3.5

	LR	HR
Atmos. Res.	~0.5° / 26L	~0.5° / 26L
Ocean Res.	~1.0° / 42L	~0.1° / 42L
Initial Condition	Coarse res. CCSM3.5 present day control	Coarse res. CCSM3.5 present day control
Integration Length	~155 yr last 100 yrs and 20 yrs analyzed	~155 yr last 100 yrs and 20 yrs analyzed

Key Points

- Observed variability in sea-surface height (SSH) and turbulent heat flux (THF) in the vicinity of Western Boundary Currents (WBC) and ocean fronts is more realistically simulated in a coupled model integration with an eddy resolving ocean, compared to one with a non-eddy resolving ocean

- Correlations between SSH and/or heat content (HC) and THF are dominated by ocean variability forcing an atmospheric response at small scales and the atmospheric variability forcing an oceanic response at large scales and the transition between the two regimes occurs at ~10^{o}

- Small scale heat content anomalies are more strongly and extensively correlated with precipitation in a coupled model simulation with an eddy resolving ocean, suggesting a mechanism whereby internally driven ocean variability may influence the deep atmosphere

Tomas et al. (2011)

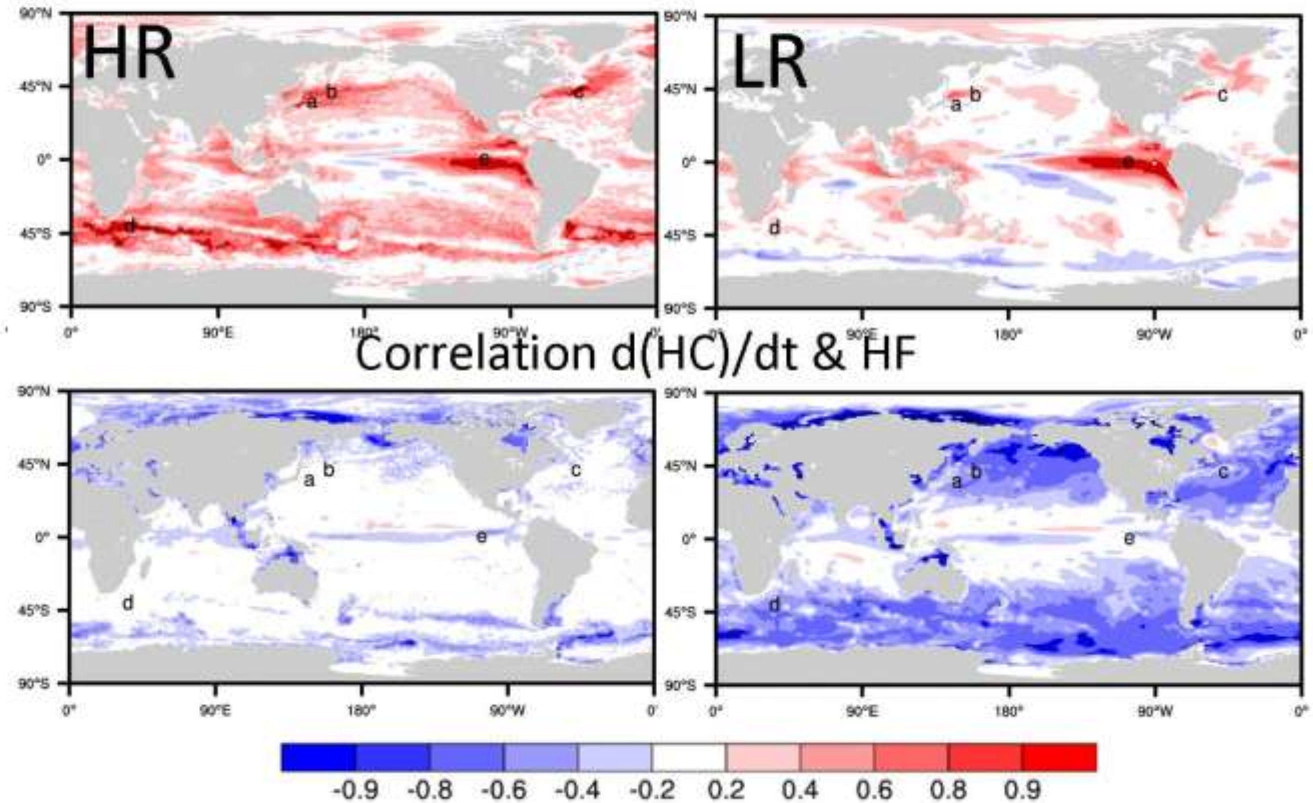
Correlations in the Coupled Simulations and Simple Model

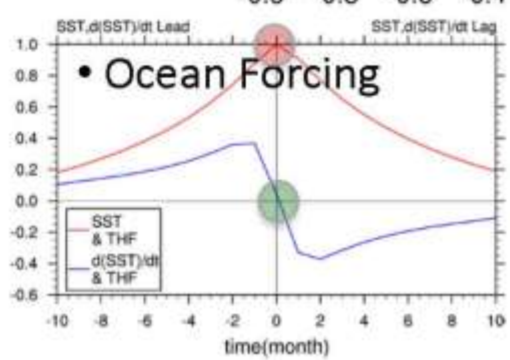
Tomas et al. (2011)

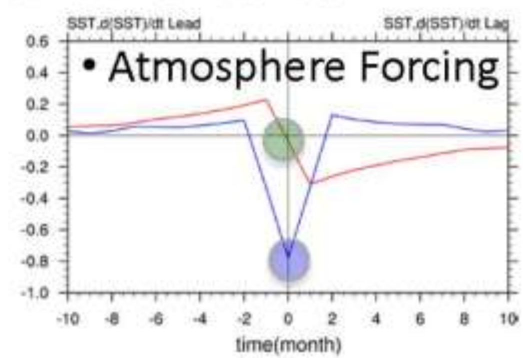
- In the HR simulation mid-latitudes, ocean variability is dominant in forcing THF
- In the LR simulation mid-latitudes, atmosphere variability is dominant in forcing THF
- In the tropics, ocean variability is dominant in forcing THF in both simulations

Note locations a,d,e

Correlations HC & HF







OCEAN PREDICTION SYSTEMS

- Short term ocean prediction systems have made significant progress over the past decade.
- GODAE: Global Ocean Data Assimilation Experiment => Routine products at ~1/10º
- Coupled prediction systems are only starting to take advantage of these systems [see Brassington et al. (2015) for a review].
- Many (including NMME) typically under-sample the ocean variability, mostly due to computational costs.

U.S. NAVY GLOBAL OCEAN FORECASTING SYSTEM

GOFS 3.0: 1/12° 32 layer HYCOM/NCODA-MVOI /MODAS synthetics/e-loan ice

- Pre-operational system that ran on Navy DSRC Cray XT5
- OPTEST report accepted by AMOP in Apr 2012

GOFS 3.01: 1/12° 32 layer HYCOM/NCODA-3DVAR/MODAS synthetics/e-loan ice

- Operational system running on Navy DSRC IBM iDataPlex computers
- Switch from MVOI to 3DVAR
- Switch from NOGAPS to NAVGEM 1.1 forcing in August 2013
- Switch from NAVGEM 1.1 to NAVGEM 1.2 forcing in March 2014

GOFS 3.1: 1/12° 41 layer HYCOM/NCODA-3DVAR/ISOP synthetics/CICE

- Add nine near surface layers
- Two-way coupled HYCOM with Los Alamos CICE model
- Replace MODAS synthetics with Improved Synthetic Ocean Profiles
- Validation test report completed

GOFS 3.5: 1/25° 41 layer HYCOM/NCODA-3DVAR/ISOP synthetics/CICE/tides

- Increase equatorial horizontal resolution to ~3.5 km
- Tidal forcing
- Scheduled to be operational in 2016-Q4

REANALYSIS 1993-2012: 1/12° 32 layer HYCOM/NCODA-3DVAR/MODAS synthetics/e-loan ice

ESPC: T359 NAVGEM, 1/12.5° HYCOM, and CICE

Items in red are different from the preceding system

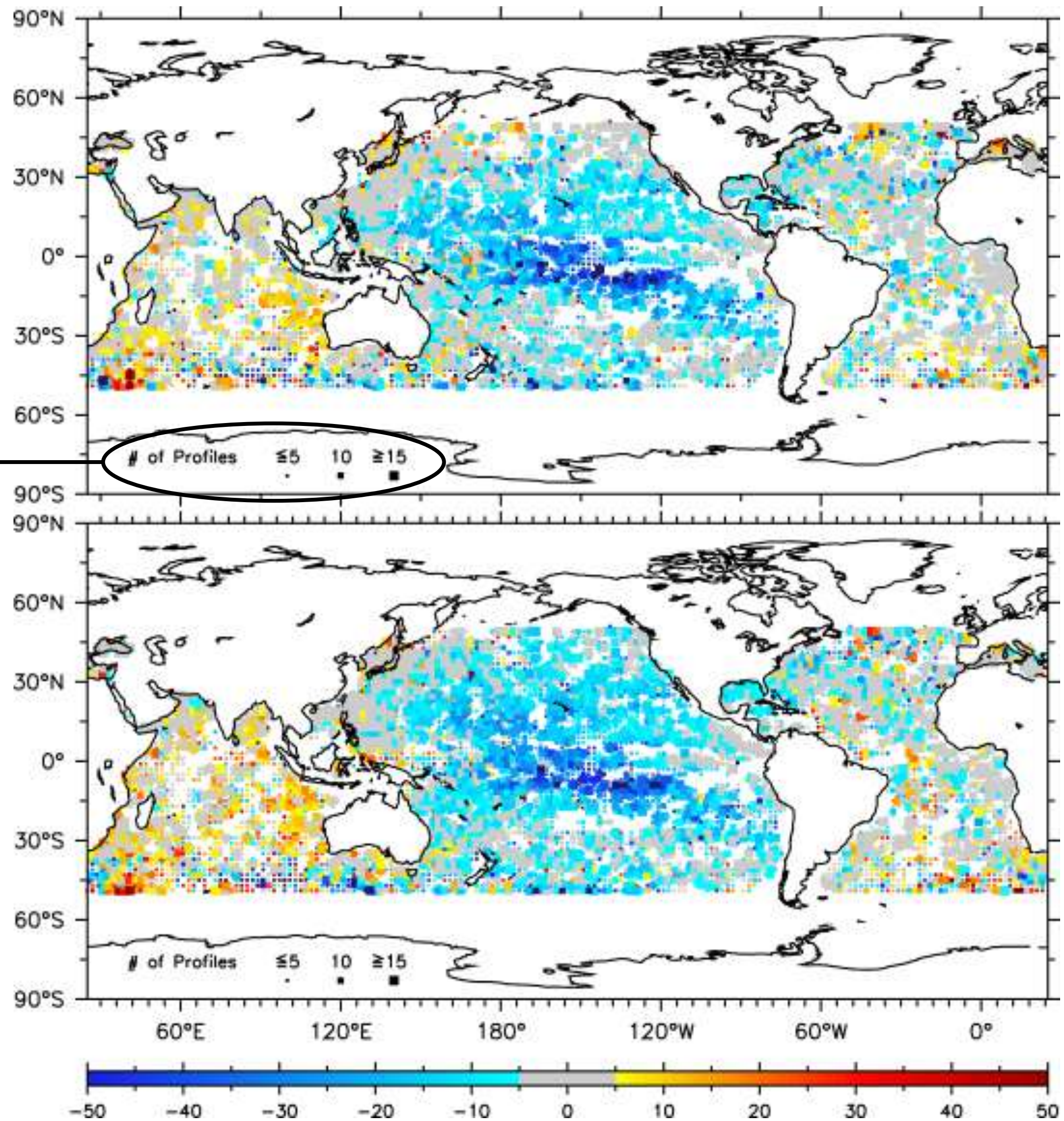
GOFS and Reanalysis outputs available at http://hycom.org

OCEAN VALIDATION – MIXED LAYER DEPTH

Median Bias Error

2° bins

Box size indicates observation count



GOFS 3.1
MdBE = -1.8 m
RMSE = 31.9 m

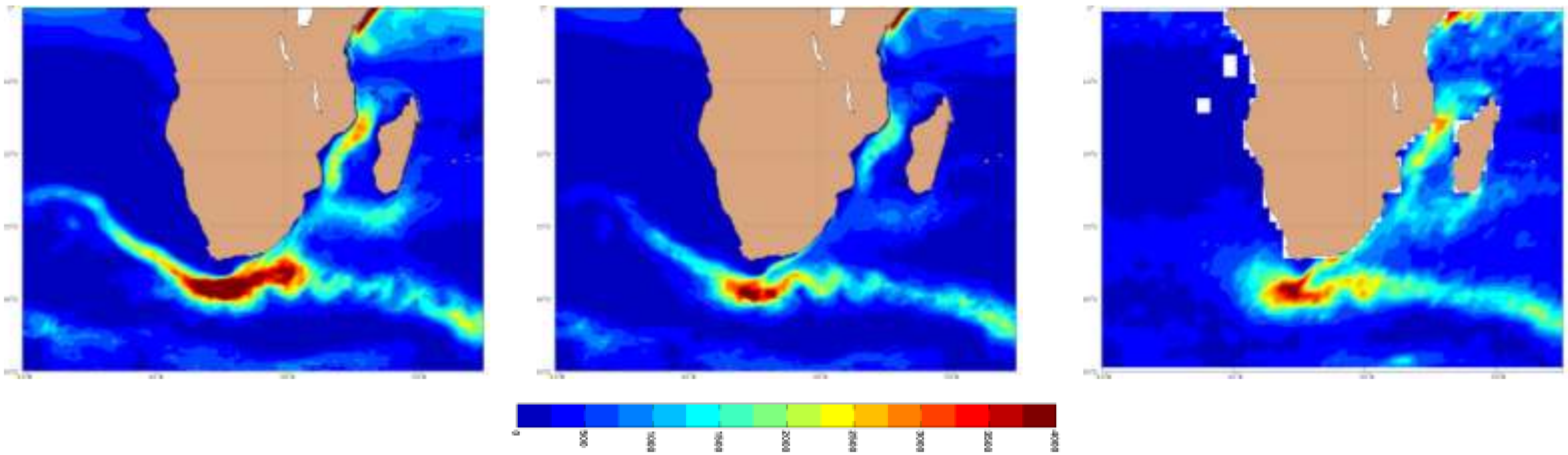
GOFS 3.0
MdBE = -3.1 m
RMSE = 36.7 m

IMPORTANCE OF AIR-SEA INTERACTIONS

- Climate/seasonal ocean models scaled down to higher resolution do not necessarily have the correct upper ocean parameterizations => need need to have metrics and increased communication with the GODAE community.
- Example: In line wind stress (Shriver et al., 2015)
    - The bulk parameterization for wind stress includes (T_{air}-SST) and 10 m winds (U10)
    - Usually calculated off-line on the NWP (e.g. NAVGEM) grid using NWP SST
    - Evidence that U10 should be replaced with (U10-U_{ocean})
    - HYCOM now has option to read in 10m winds and calculate wind stress in-line
    - CICE also reads in U10 for ice-atmosphere stress and gets U_{ocean} from HYCOM for ice-ocean stress.

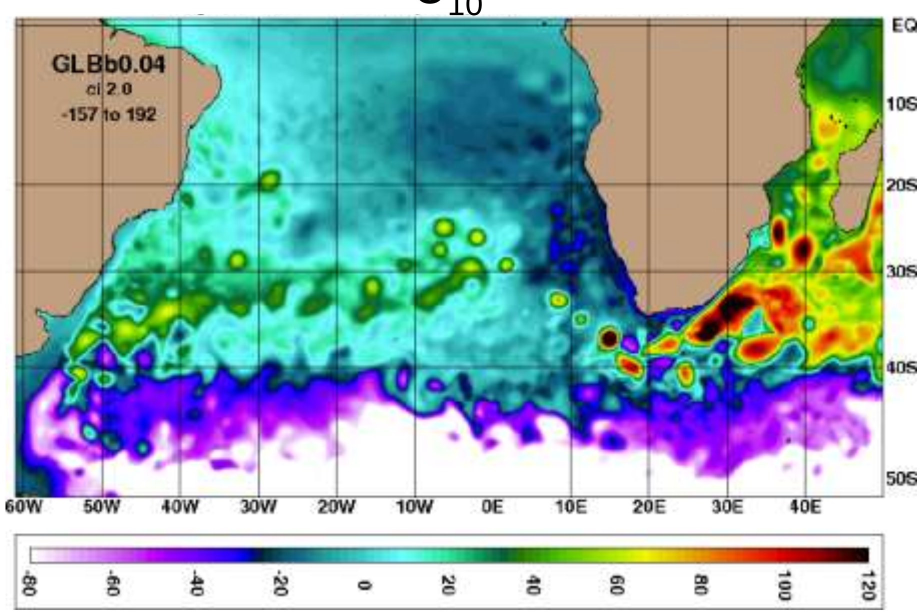
1/12° global 2003-2007 surface EKE (per unit mass)

standard stress formulation | **stress formulation including wind-current shear** | **drifter observations**

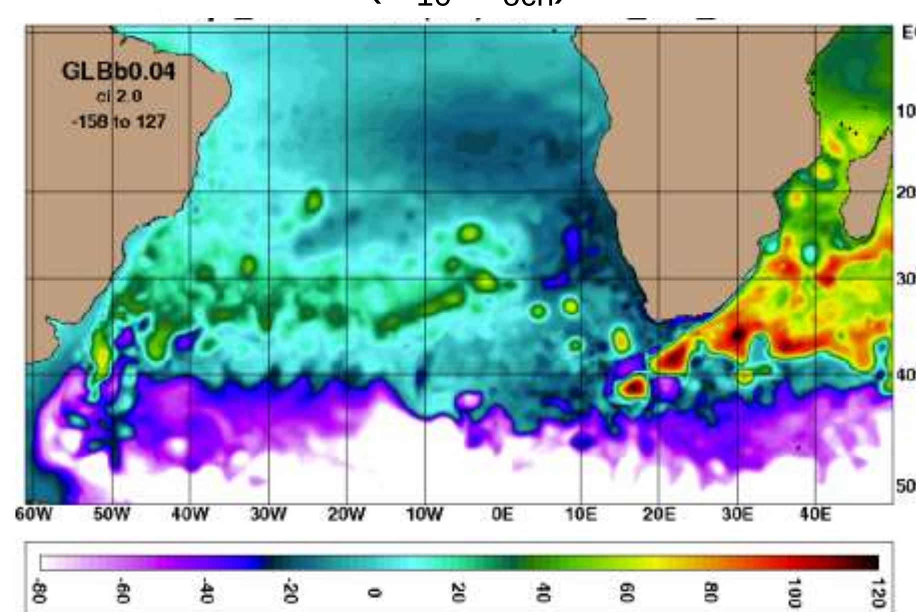


1/25° global HYCOM+CICE Agulhas rings

SSH (cm) from off-line stress U_{10}



SSH (cm) from in-line stress $(U_{10}\text{-}U_{ocn})$



COUPLED DATA ASSIMILATION

- Assimilation into a coupled model where observations in one medium are used to generate analysis increments in the other [minimization of a joint cost function with controls in both media].
- Loosely (weakly) coupled: the first guess (background) for each medium is generated by a coupled integration.
- Reduced systems: atmosphere with corrections in ocean mixed layer model; ocean with correction of surface fluxes.

Rienecker (2010)

DRIVERS FOR COUPLED DATA ASSIMILATION

- Ocean analyses: inadequacy of surface fluxes from atmospheric analyses
- Needed to reduce initialization shocks
- Needed for better surface boundary estimates for atmospheric analyses
- Needed for an optimal representation of the oceanic and atmospheric surface boundary layers.

SUMMARY/CONCLUSIONS

- On S2S time scales, can we computationally afford high resolution ocean numerical models?
- Can we quantify the impact of eddy resolving ocean on S2S time scales?
- SST representation depends on the surface mixed layer representation and associated parameterizations. Should a wave model be incorporated?
- Consistent coupled data assimilation is needed for an optimal representation of the oceanic and atmospheric surface boundary layers.
- Coupled prediction will have a significant impact on many ocean applications (sonar prediction, search and rescue, chemical spills, etc.)